

for designing optimum FIR linear phase digital filters"

- Copy of reference paper on the eigenvalue algorithm by Vaidyanathan and Nguyen entitled "Eigenfilters: A new approach to least-squares FIR filter design and applications including Nyquist filters"
- Copy of reference paper by T. Blu on "A new design algorithm for two-band orthogonal rational filter banks and orthogonal rational Wavelets",
- Copy of reference paper by K. C. Ho et.al. on "Optimum discrete Wavelet scaling and its application to delay and doppler estimation".

REMARKS

1.Detailed Action

This communication is responsive to your office action mailed on 12/08/2006

2.Detailed Action

Of claims 5-12 pending in this application, claims 9,11 are deleted and claims 7,8,11,12 are amended.

3. Information Disclosure Statement

Included in the information disclosure statement are copies of the paper on the Remez-Exchange algorithm by McClellan, Parks, and Rabiner entitled "A computer program for designing optimum FIR linear phase digital filters", the paper on the eigenvalue algorithm by Vaidyanathan and Nguyen entitled "Eigenfilters: A new approach to least-squares FIR filter design and applications including Nyquist filters", the paper by T. Blu on "A new design algorithm for two-band orthogonal rational filter banks and orthogonal rational Wavelets", and the paper by K. C. Ho et.al.

on ""Optimum discrete Wavelet scaling and its application to delay and doppler estimation "".

4. Drawings

The claims and figures have been amended to comply with 37 CFR 1.83(a) in that the figures now show every feature of the invention specified in the claims. Figure 5 has been replaced with amended figure 5, new figure 6, and new figure 7 which respectively describe the eigenvalue algorithm, least-squares algorithm, and an application which uses the mother Wavelet designed by these algorithms. The algorithms in figures 4,5 design a Wavelet at baseband referred to as the mother Wavelet using M digital samples per Wavelet repetition interval for application to a communications channel defined in figure 3. This channel is designed to be the baseband channel in an M channel filter bank wherein the complex digital sample rate over the filter bank bandwidth is equal to the Nyquist sample rate $1/T$ which means M is also equal to the number of channels in this filter bank. The application changes the number of channels to $M2^p$ wherein p is an integer referred to as the scaling parameter for Wavelets and changes the sampling rate to $2^p/T$, while using the design for the mother Wavelet. This design is specified by the set of design harmonics $\psi(k)$ which typically are a small subset of the available $\psi(k)$. As described in the new figure 7 the new baseband Wavelet $\psi(n)$ for this application is derived from the mother Wavelet by solving equations (9),(11),(20) in the specification when modified by replcing the folded-over harmonics $h_f(k)$ with $\psi(k)$, using the number of samples per Wavelet spacing $M2^p$ wherein n is the sample index for the new sample rate $2^p/T$. Figures 5,6,7 restate the algorithms derived in somewhat greater detail in the specification.

5. Claim Objections

Claims 9,11 are deleted and claims 7,8,10,12 are amended. Claim objections and mistakes have been appropriately corrected in the amended claims.

6. Claim Rejections - 35 USC § 112

Currently amended claims 7,8,10,12 are now believed to particularly point out and distinctly claim the subject matter which I regard as my invention.

7. Claim Rejections - 35 USC § 112

Claims 7,8,10,12 have been amended to correct the indefinite limitations and to particularly point out and distinctly claim the subject matter which I regard as the invention. Amended claims 7 and 8 describes how to design a digital mother Wavelet at baseband and its application to communications using different algorithms in 7 and 8. Claim 10 has been amended to describe a multi-resolution application to a digital filter bank for communications. Claim 12 has been amended to describe Wavelet properties for applications.

8. Claim Rejections - 35 USC § 101

Claims 7,8,10,12 have been amended for application to communications transmitters and receivers thereby satisfying 35 USC § 101 requirements that "Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter⁴, or any new and useful improvement thereof, may obtain a patent therefore, subject to the conditions and requirements of this title."

9. Claim Rejections - 35 USC § 101

Claims 7,8,10,12 have been amended for application to communications transmitters and receivers thereby satisfying the requirement that the invention be directed toward statutory

matter. Claim 7 has been amended to describe the steps and procedures to design a digital mother Wavelet at baseband using an iterative eigenvalue algorithm and to describe the application to communications transmitters and receivers. In claim 8 the amended claim describes the steps and procedures to design a digital mother Wavelet at baseband using a gradient search algorithm and describes the application to communications transmitters and receivers. Claim 10 has been amended to describe a multi-resolution application of the mother Wavelets in claim 7 or 8 to a polyphase digital filter bank for communications. Claim 12 has been amended to describe Wavelet properties for applications.

10. Response to Amendment

Claims 7,8,10,12 have been amended to eliminate any new matter not found in the original specification. Claim 7 corresponds to amended FIG.5, claim 8 corresponds to new FIG. 6, claim 10 corresponds to new FIG. 7, claim 12 properties are those clearly pointed out in the original specification, and the amended figures 5,6,7 summarize algorithms clearly described in the original specification.

Inserted portion in pages 43-44 have been deleted in the specification.

11. Response to Arguments

Amended drawings, claims 7,8,10,12, specification, and enclosure of referenced papers, are intended to address the office actions and objections. I have responded to these actions and objections to the best of my abilities.

12. Response to Arguments

I have no disagreements with the examiner's contentions and have amended drawings, claims 7,8,10,12, and specification to address the examiner's contentions. The following discussion of the references applied to the claims explain how the claims avoid the references or distinguish from them.

Consider the reference to the Remez-Exchange algorithm by McClellan, Parks, and Rabiner entitled "A computer program for designing optimum FIR linear phase digital filters" This algorithm designs a linear-phase FIR filter impulse responses $FIR(n)$ using the Parks-McClellan algorithm which in turn uses the Remez exchange algorithm and Chebyshev approximation theory to design filters with an optimal fit between the desired and actual frequency responses. The filters are optimal in the sense that the maximum error between the desired frequency response and the actual frequency response is minimized. Filters designed this way exhibit an equiripple behavior in their frequency responses and hence are sometimes called *equiripple* filters. These linear phase filters are specified by their passband, ripple across their passband, and the deadband separating the passband and stopband. The design minimizes the squared error across the unity level passband where the error is due to the ripple and rolloff and across the zero level stopband. The digital mother Wavelet in claim 8 and FIG. 6 reformulates the error metrics for the stopband and passband as norm-squared least-squares (LS) error metrics $J(stop)$, $J(pass)$ in the Wavelet FIR $\psi(n)$, adds the Wavelet requirement on the deadband as a norm-squared LS error metric $J(dead)$ in $\psi(n)$, adds the Wavelet requirements on the intersymbol interference (ISI) as the non-linear norm-squared LS error metric $J(ISI)$ in $\psi(n)$, and adds the Wavelet requirement on the adjacent channel interference (ACI) as the non-linear norm-squared LS error metric $J(ACI)$ in $\psi(n)$. To complete the specification of the Wavelet FIR $\psi(n)$ the constituent error

metrics are converted to norm-squared error metrics in the design harmonics $\psi(k)$ of the FIR $\psi(n)$ in order that the Wavelet exhibit the multi-resolution property whereby all of the Wavelets at multi-resolutions are derivable from the mother Wavelet by a scaling operation described in the specification, in FIG. 7, and in claim 10. The optimum design minimizes the norm-squared error weighted sum J of the $J(\text{pass})$, $J(\text{stop})$, $J(\text{dead})$, $J(\text{ISI})$, $J(\text{ACI})$ with respect to $\psi(k)$ us a least-squares gradient search algorithm which is initialized by the Remez-exchange algorithm to speed up the convergence. This optimum $\psi(k)$ is converted by the inverse Fourier transform mapping to the corresponding $\psi(n)$. Tests have demonstrated that the performance is significantly improved in FIG. 8, supports the design of zero-excess bandwidth filters, supports applications to bandwidth efficient modulation in FIG. 9 and synthetic aperture radar in FIG. 10. In FIG. 9 the Remez-Exchange performance is not shown since it is widely known to be considerably poorer than the square-root raised cosine (sqrt) filters being compared with in the figure.

Consider the reference to the eigenvalue algorithm by Vaidyanathan and Nguyen entitled "Eigenfilters: A new approach to least-squares FIR filter design and applications including Nyquist filters" It is well-known that the eigenvalue algorithm can be used to find the optimum solution which minimizes the quadratic least-squares error metric. The algorithm finds the minimum eigenvalue and the corresponding eigenvector which minimizes the least-squares error metric. Vaidyanathan and Nguyen used this algorithm to design a linear-phase FIR filter impulse responses $FIR(n)$ for the same application to a digital filter bank as the Remez-Exchange algorithm and constructing the error metrics for the stopband and for the passband as quadratic functions of the errors across the passband and across the stopband. The weighed sum J of these two metrics is minimized by the eigenvalue algorithm to find the optimum impulse response

FIR(n). The digital mother Wavelet in claim 7 and FIG. 5 generalizes the error metrics for the stopband and passband as quadratic (LS) error metrics $J(\text{stop})$, $J(\text{pass})$ in the Wavelet FIR $\psi(n)$, adds the Wavelet requirement on the deadband as a quadratic LS error metric $J(\text{dead})$ in $\psi(n)$, adds the Wavelet requirements on the intersymbol interference (ISI) as the non-linear quadratic LS error metric $J(\text{ISI})$ in $\psi(n)$, and adds the Wavelet requirement on the adjacent channel interference (ACI) as the non-linear quadratic LS error metric $J(\text{ACI})$ in $\psi(n)$. To complete the specification of the Wavelet FIR $\psi(n)$ the constituent error metrics are converted to quadratic error metrics in the design harmonics $\psi(k)$ of the FIR $\psi(n)$ in order that the Wavelet exhibit the multi-resolution property whereby all of the Wavelets at multi-resolutions are derivable from the mother Wavelet by a scaling operation described in the specification, in FIG. 7, and in claim 10. The optimum design minimizes the quadratic error weighted sum J of the $J(\text{pass})$, $J(\text{stop})$, $J(\text{dead})$, $J(\text{ISI})$, $J(\text{ACI})$ with respect to $\psi(k)$ using an iterative eigenvalue algorithm in order to incorporate the non-linear $J(\text{ISI})$, $J(\text{ACI})$. The optimum $\psi(k)$ is converted by the inverse Fourier transform mapping to the corresponding $\psi(n)$. Tests have demonstrated that the performance is significantly improved in FIG. 8, supports the design of zero-excess bandwidth filters, supports applications to bandwidth efficient modulation in FIG. 9 and synthetic aperture radar in FIG. 10. In FIG. 9 the Valdyanathan and Nguyen performance is not shown since it is widely known to be considerably poorer than the square-root raised cosine (sq-rt) filters being compared with in the figure.

Consider the reference to the paper by T. Blu on "A new design algorithm for two-band orthogonal rational filter banks and orthogonal rational Wavelets". Blu derives an iterative algorithm to solve for the polyphase filter transfer function

that provides an approximate solution to the orthogonality requirement for a two-band filter. Referring to FIG. 3 used to derive the mother Wavelet, Blu's two band filter configuration consists of the baseband filter and the filter for the second channel at the radian frequency spacing $2\omega_s$. This means he does not directly consider the problem addressed in the invention disclosure of designing waveforms for contiguous filters and which means his analysis is not relevant to the specification. Continuing with Blu's analysis, this topology allows Blu to state the orthogonality condition on the two filters with fractional bandwidths allowed by his use of rational functions, as a polyphase equation in the filter coefficients. This orthogonality condition is required for both Wavelets and for perfect reconstruction. Blu's algorithm solves the equations for orthogonality to obtain an approximate solution. The mother Wavelet in this invention disclosure is designed for orthogonality and perfect reconstruction properties (deadband, ISI, ACI, properties) for a finite length Wavelet constrained to meet communications requirements on the passband, stopband, deadband, ISI, ACI as well as having multi-resolution scaling properties. Note that the mother Wavelet in this invention disclosure is the best possible waveform for the design constraints. This means that if the length constraint on the mother Wavelet in this invention disclosure were removed as in Blu's analysis, the filter response would be at least as good as Blu's.

Consider the reference to the paper by K. C. Ho et.al. on "Optimum discrete Wavelet scaling and its application to delay and doppler estimation ". Ho et.al. derives an optimum algorithm for time delay estimation and doppler frequency estimation using scaled Wavelets with a maximum-likelihood (ML) estimator. The end result is that Ho et.al. are able to perform these estimates with a performance that matches the Cramér-Rao lower bound (CRLB) that defines the optimum performance, for signal-to-noise

ratios greater than about -4 dB. Although not addressed in the specification, the original intent was to include a presentation on the performance of the mother Wavelet in supporting the derivation of optimum error discriminates and estimators for time synchronization and delay and for frequency synchronization and doppler estimation which would be as good as the CRLB bound which applies to all values of signal-to-noise. Unlike the ML estimators of Ho et.al. the discriminants and estimators derived from the mother Wavelets are designed to be used in coherent and non-coherent tracking and synchronization loops in support of communications and radar whereas Ho et.al. are addressing ML formulations of limited application value. A motivation for multi-resolution Wavelets was in part dictated by the performance of the error discriminates and estimators realized by the mother Wavelets of this invention disclosure.

Thanks for all of your help and guidance.

Sincerely,



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TITLE OF INVENTION: Wavelet Multi-Resolution Waveforms

INVENTOR: Urbain A. von der Embse

Currently amended DRAWINGS AND PERFORMANCE DATA

APPLICATION NO. 09/826,118

INVENTION: Wavelet Multi-Resolution Waveforms

INVENTOR: Urbain A. von der Embse

DRAWINGS AND PERFORMANCE DATA